

Comparison of the light transmission in protecting films used in laser photodynamic therapy

Background: The use of therapeutic laser equipment requires care to avoid cross-contamination of microorganisms, requiring coating with a material that preferably has minimal beam attenuation.

Aim: To determine what type of material should be used to wrap the instrument to prevent contamination while still providing an adequate dose level during the procedure.

Methods: Polyvinyl chloride (PVC) films, condoms, plastic bags, latex surgical gloves and kinesiology tape were investigated through spectrophotometry on the ultraviolet-visible-near infrared range of the optical spectrum. Transmittance data were compared among these materials to identify the least-blocking membrane.

Results: PVC films presented the highest transmittance, followed by plastic bags. Gloves and kinesiology tape strongly attenuated the optical radiation.

Conclusion: PVC films should be the first choice for wrapping the laser emitter. Latex gloves are adequate for operator use to decrease risks from chronic exposure. Laser application over kinesiology tape results in strong beam attenuation.

Since the invention of the laser more than 80 years ago, several uses have been developed, especially in the medical sciences. Despite not being an ionising radiation, its high intensity can induce photochemical reactions and affect cellular metabolism and signalling pathways (Hawkins, 2009). Research into the interaction of the laser photons with living, especially in the red and near-infrared bands, has revealed non-thermal effects capable of influencing cell proliferation (Karu, 2003). This biostimulation process can accelerate the healing of chronic wounds and impact nerve injury recovery. Chronic wounds are defined as those that fail to progress through the four stages of wound healing and are often associated with debilitating chronic illnesses, such as diabetes. Laser irradiation can be used to improve wound healing (Lucena, 2021). The results, however, depend on the patient's own wound-healing capacity, something outside of the health professional's control. The factors that can be adjusted during laser irradiation are wavelength, energy density, power and treatment time. At present, there is no universally accepted protocol for setting these four parameters (Miranda, 2025), meaning that laser therapy often relies heavily on the operator's experience. Historically, other medical techniques involving electromagnetic

fields were used routinely before standardised protocols were established (Capaverde, 2012). Another factor, rarely addressed in the scientific literature, is the prevention and control of laser emitter contamination.

While laser therapy is considered a non-contact treatment and should, in principle, be free from beam-source contamination, treating open wounds carries the risk of accidental contact between the laser emitter and patient body fluids, which may be contaminated. To prevent this, manufacturers often recommend wrapping the laser emitter in a polymeric pellicle, most commonly domestic polyvinyl chloride (PVC) film. This practice is widespread in healthcare institutions; however, the optical properties of such wrapping often receive limited attention from practitioners. A film that appears perfectly transparent to the human eyes does not necessarily transmit all visible light, nor does it guarantee unimpeded transmission of infrared light. Even different brands of films may have distinct optical properties.

In this work, we propose a comparative assessment of the optical properties of several materials commonly available in healthcare institutions that are used to wrap laser emitters.

Materials and methods

Nine different materials were characterised

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- Prevention and control

for light transmission: two brands of PVC film (Lusafilm and Tecfilm), three brands of latex surgical gloves (Cremer, Medix and Live), two non-lubricated condoms (Madeitex and Blowtex), a plastic bag made of low-density polyethylene (LDPE) and a kinesiology tape (KBand). These materials are commonly available in healthcare institutions.

The transmission spectra of all nine materials were measured using a spectrophotometer (Varian, Cary 50) from 190 nm to 1100 nm, covering the range from the middle ultraviolet to the near infrared. The spectrophotometer was allowed to warm up for at least 30 minutes before measurements. Transmittance measurements were performed at 1 nm intervals. A single layer of each pellicle was placed in the optical path of the laser within the dark chamber of the spectrophotometer. This thickness mimics the wrapping arrangement used during actual laser application to patients.

Transmittance τ is defined as the ratio of the light intensity that passes through a substance I to the initial incident intensity I_0 :

$$\tau = I/I_0$$

Equation 1

which is integrated over a broad band of the spectrum. The spectral transmittance τ_λ is defined for each individual wavelength λ .

Several international guidelines on non-ionising radiation protection (IEC60825-1, ANSI Z156) use the optical density concept, which is defined by the following equation:

$$D_\lambda = -\log_{10} \tau_\lambda$$

Equation 2

The minus sign in **Equation 2** guarantees that the optical density is a positive value because the transmittance given by **Equation 1** is less than one, and the logarithm in **Equation 2** would return a negative value. Thus, the optical density is always positive. The $\log_{10}$ function has the property that if its argument increases tenfold, the resulting value increases by only one unit. Therefore, **Equation 2** is preferred over **Equation 1** to define light attenuation by low-transparency materials because, mathematically, it provides better resolution for very low light transmission. Typically, the highest optical density found in personal protective equipment is seven, which means a transmittance of 10^{-7} .

In **Equation 2**, the subscript λ implies that since transmittance depends on wavelength, the same applies to optical density. Hence, a broadband optical density can be defined for the material that composes the wrapping film. However, when a laser beam is employed in a procedure, its

radiation is monochromatic, so the optical density value that truly matters is that corresponding to the specific laser wavelength. Therefore, to quantify the amount of optical radiance that effectively reaches the target, it is necessary to compare the optical density of each material at that single wavelength of interest.

Results

Figure 1 shows the transmission spectra of all nine studied materials. The vertical axis represents transmittance as a percentage, corresponding to the values given by **Equation 1** multiplied by 100%. Line colours indicate the type of pellicle material, as described in the figure's caption. Measurements were performed across the full range the spectrophotometer could sweep. The superimposed curves at the bottom of the graph indicate considerable opacity of those materials over the whole measurement range.

Small fluctuations in transmittance are due to random noise and are particularly apparent in the top curves of **Figure 1**. Optical density can be easily calculated by applying **Equation 2** to the spreadsheet containing the measured data shown in **Figure 1**. When the logarithm function of **Equation 2** is applied to the high transmittance data, i.e., the more transparent materials, the resulting curves appear smoothed. On the other hand, less transparent materials exhibit significant random fluctuations, as observed in the top curves of **Figure 2**. This suggests that while the logarithm function compresses its output values as the argument increases, it spreads fluctuations when the argument is decreased. In other words, when transmittance is very low, the fluctuations become comparable to the intrinsic uncertainty of the measurement, and small fluctuations in the instrument output are amplified by the logarithmic transformation.

Discussion

When a radiation beam passes through a material, its intensity decreases exponentially as a function of the penetration depth x and the attenuation coefficient, α_λ . This behaviour is described by the mathematical expression:

$$I = I_0 e^{-\alpha_\lambda x}$$

Equation 3

The films studied in this work have typical thicknesses x ranging from 0.01 mm for the PVC films to 0.16 mm for the kinesiology tape. Their attenuation coefficients vary because each material is composed of diverse compounds (latex, PVC, LDPE, etc.). Since the analysed substances are homogeneous, the exponent term in **Equation 3** can be simplified into a single parameter: the optical density, D_λ . This approach

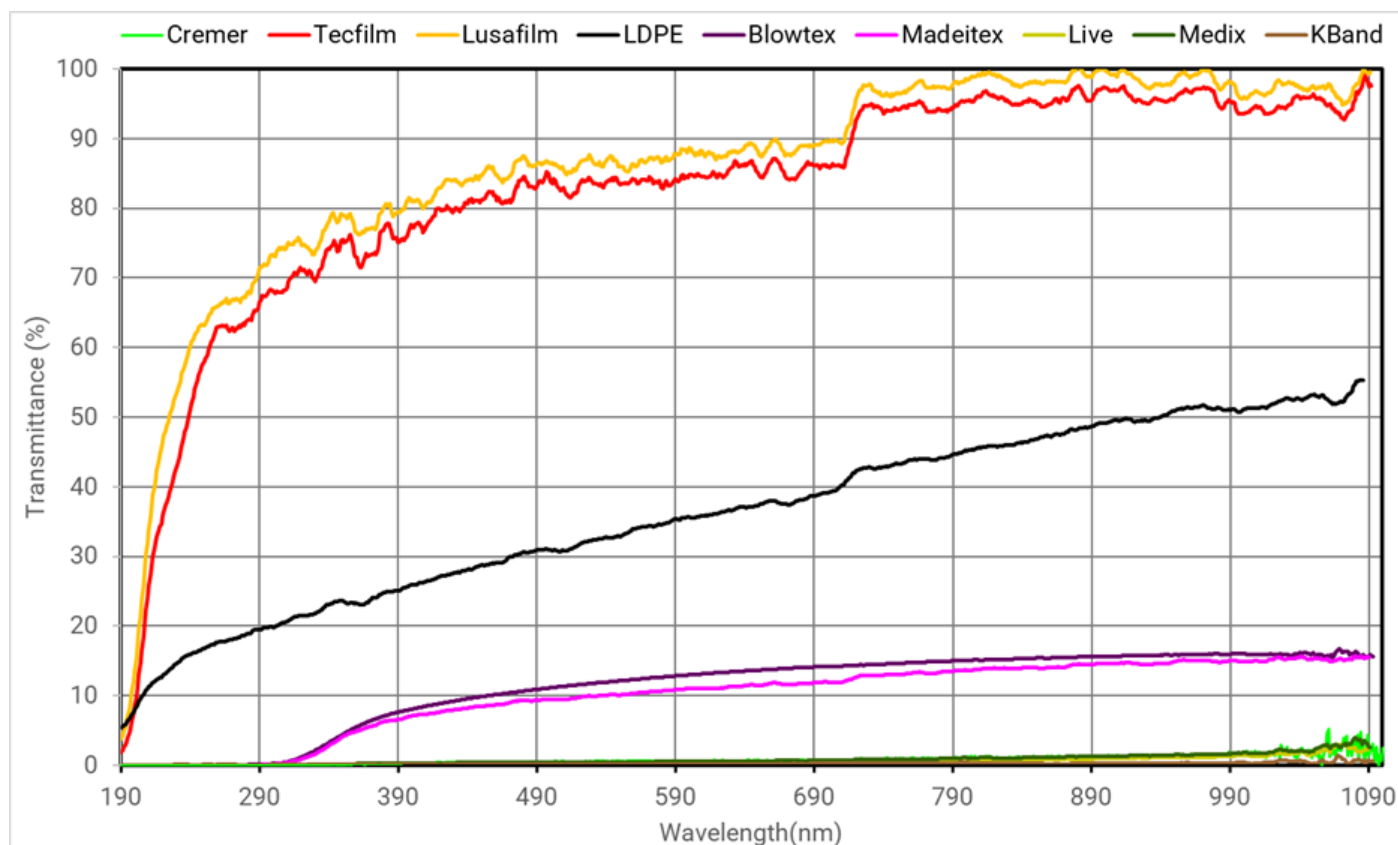


Figure 1

Figure 1. Transmittance spectra of the nine studied materials.

has the advantage of combining both the material thickness and its optical properties into one parameter.

Taking this into consideration and swapping the natural logarithm with the base 10 logarithm, **Equation 3** becomes:

$$I = I_0 10^{-D_\lambda}$$

Equation 4

from where **Equation 2** can be retrieved. **Equation 4** shows that the beam intensity decreases exponentially as it travels through the irradiated medium. The higher the optical density, the greater the beam attenuation.

Protection issues during therapeutic procedures must be considered from two perspectives: personnel and equipment.

Regarding personnel protection, both the patient and the laser operator must use appropriate personal protective equipment to avoid unnecessary radiation exposure. The patient typically wears fully opaque eye protection that blocks all wavelengths of optical radiation. The rest of the body is covered with a blocking fabric, except for the area undergoing treatment.

The laser operator, who is often repeatedly exposed to laser radiation, must be particularly mindful of protective measures. Eyes must be protected by goggles, and hands must be protected with gloves of high optical density.

Protective goggles must have the special characteristic of blocking the hazardous laser wavelength while allowing the passage of other wavelengths, so the operator can clearly see the treatment site.

The optical density symbol carries a subscript to indicate that it may, and in protective devices, it typically does, depend on the radiation wavelength. The mathematical approach described earlier facilitates the labelling of protective goggles with a single number corresponding to the type of laser emitter employed in the procedure. International standards (IEC60825-1, ANSI Z156) define the minimum optical density that protective goggles must have, depending on the laser wavelength, energy and irradiation time to guarantee adequate eye protection for the operator. Among other recommendations, these standards advise placing a sign on the treatment room door reading "Laser in Use".

Regarding equipment protection, the laser emitter must be isolated from contamination, as discussed in Section 1. However, placing a contamination-preventive material in the optical path attenuates the beam and interferes with the dose delivered to the patient. The ideal solution would be to use a protective material with zero optical density. Practically, the operator should choose from the available materials the one exhibiting the lowest optical density at the wavelength used in the procedure.

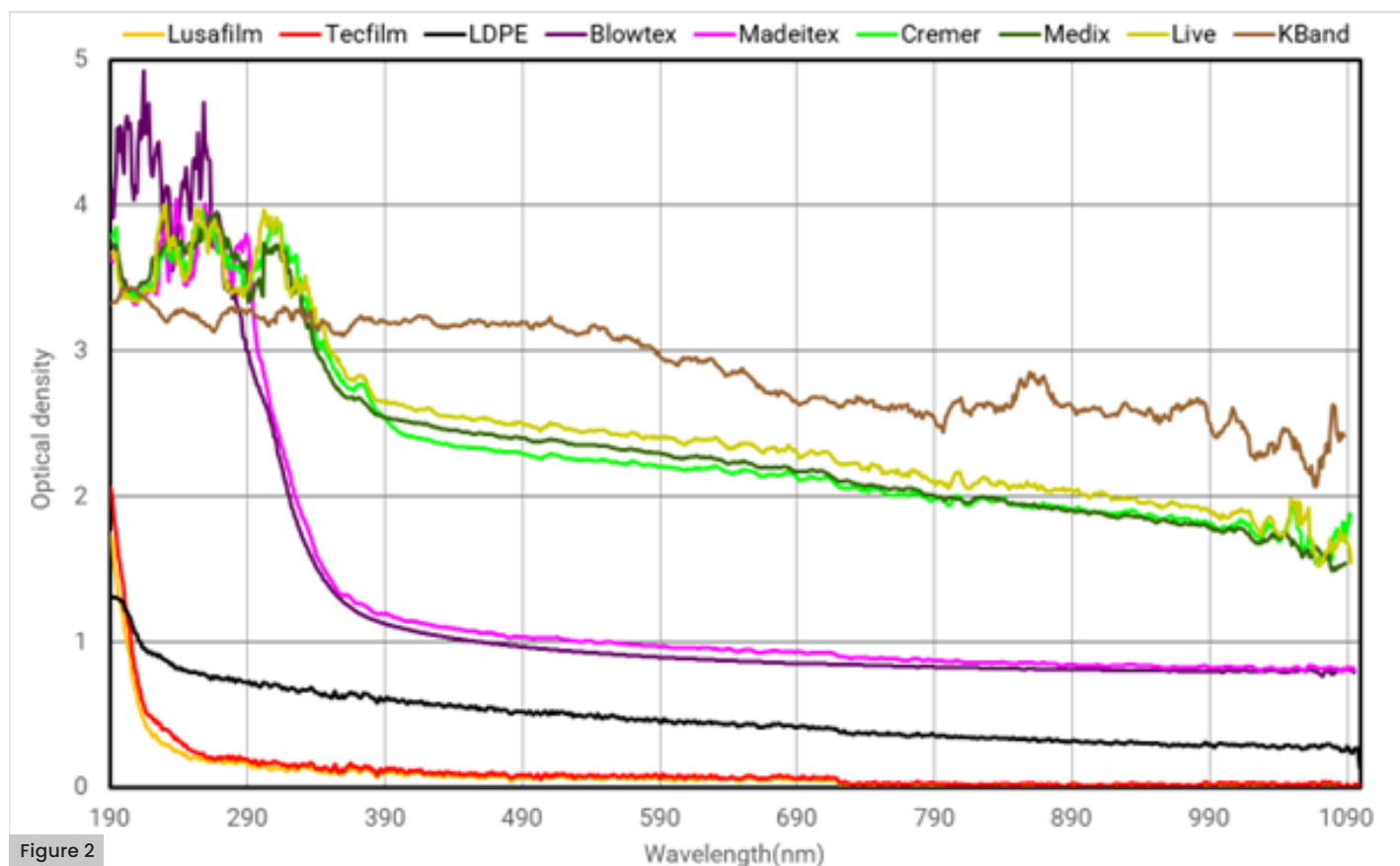


Figure 2

Each type of therapy requires a specific laser wavelength. For example, diabetic foot ulcers are typically treated with wavelengths of 660 nm and 808 nm. Referring to these values on the spectra in **Figure 1**, the best protective materials are indeed the PVC films, as they have the highest transmittance, Lusafilm presenting a slightly higher transmittance than Tecfilm. In the near ultraviolet region, PVC films still have considerable optical density, but in the middle ultraviolet, they effectively block radiation.

The use of LDPE plastic bags is common in odontological procedures. **Figure 1** shows that LDPE presents an almost linear increase in transmittance toward the near infrared. Nonetheless, some attenuation of the laser radiation occurs with its use.

Condoms are commonly used to wrap laser emitters; after all, they are specifically designed to prevent contamination. However, their low transmittance works against their use in laser therapy. In the UVB part of the spectrum, condoms exhibit near-zero transmittance, effectively blocking this type of radiation.

Other materials, namely latex gloves and kinesiology tape, present very low transmittance across the optical spectrum and their curves are compressed near the bottom of the graph. To observe their detailed spectra, it is necessary to refer to the optical density spectra shown in **Figure 2**.

The three brands of latex gloves present optical densities close to or above two throughout the visible spectrum. For comparison, laser emitters used in wound therapy typically have a power of around 100 mW. Protective goggles for this wavelength and power range must have an optical density of around two. Therefore, surgical gloves provide a level of protection comparable to that required to protect the eyes, which are much more delicate than skin. Thus, these gloves should be worn by the operator to avoid chronic exposure, but are not suitable for protecting the laser emitter.

The kinesiology tape was included in this study for a different reason than the membranes discussed above. Its use is quite common in cases where there is a skin wound in the area where the tape is applied. A health professional may wonder if the wound could be treated without removing the tape. Unfortunately, this is not the case. The spectrum shown in **Figure 2** reveals an optical density near three, implying very low transmission of the laser beam. Therefore, we do not recommend using laser therapy through kinesiology tapes due to their ineffectiveness.

Before initiating treatment, the radiation dose must be defined. In laser therapy, this usually involves establishing the amount of energy (in joules) delivered to the tissue. For a laser emitter with constant power, the healthcare professional adjusts the application time (in seconds or

Figure 1. Optical density spectra of the nine studied materials.

Table 1. Dose correction

	Compensation factor (%)	
	660 nm	808 nm
Lusafilm	9.0	7.6
Tecfilm	10.5	9.3
LDPE	16.1	12.7
Blowtex	33.6	31.5
Madeitex	55.6	50.0
Cremer	78.4	66.8
Medix	75.5	69.0
Live	71.5	68.7
KBand	77.5	78.9

minutes). When the emitter is wrapped with a film that reduces the dose reaching the wound, a correction to the applied dose is necessary. This correction depends on the wrapping material and the laser wavelength.

Table 1 shows the compensation factors for all nine materials investigated in this work, for illustrative wavelengths of 660 nm and 808 nm. The films at the top of the table are suitable for use in procedures, provided the respective compensation factor is applied. For example, if a procedure using a 660nm laser with Lusafilm as the emitter wrapping, the irradiation time must be increased by 9.0% to deliver the intended dose. The substances at the bottom of the table should be avoided as wrapping films because their compensation factors are too high, meaning the exposure time would need to be increased significantly. Nonetheless, these materials are suitable for protecting the operator from chronic laser exposure.

The values listed in Table 1 were obtained as follows. Due to random noise causing fluctuation in the transmittance and optical density spectra, directly reading values from the spectra is prone to error. Thus, it is advisable to perform some smoothing near the wavelength of interest. The wavelength uncertainty of therapeutic lasers is typically ± 10 nm. Therefore, the transmittance at 660 nm was calculated by averaging values over the 650 nm to 670 nm interval. The same method was applied for 808 nm. This approach can be replicated for any wavelength of interest.

Conclusion

The use of wrapping films on laser emitters to prevent contamination is a protocol that should not be discouraged. However, the health

professional performing the procedure must be aware that the film affects the intensity of the transmitted light. The choice of protective material should be based on several factors: availability, effectiveness in preventing contamination, cost, ease of use and, as shown in this paper, the optical properties of the material. Preference should strongly depend on the amount of light the film can transmit at the laser wavelength of interest. Compensation for beam energy loss due to attenuation in the wrapping film must also be considered. This study presents compensation factors that can be applied to adjust procedure time for several materials commonly used in healthcare institutions.

Manufacturers of therapeutic laser emitters typically recommend PVC films as wrapping materials, and the present work confirms that this is a consistent choice. LDPE plastic bags can also be used, but require a longer application time. Condoms may be used, but they require even greater compensation times. Latex gloves are not recommended as wrapping materials, but should be used as personal protective equipment. Laser application through kinesiology tape is not recommended due to its inefficacy.

Future research on alternative materials could reveal substances with higher transmittance whilst retaining the necessary protective properties. Moreover, clinical studies evaluating patient responsiveness to dose correction based on the wrapping pellicle should be conducted. ●

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